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On the Origin of Early-type Galaxies Nuclei

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Abstract. The ACS Virgo cluster survey by Côté and collaborators shows the presence of compact nuclei at the photocenters of many early-type galaxies. It is argued that they are the low-mass counterparts of nuclei hosting Super Massive Black Holes (SBHs) detected in the bright galaxies. If this view is correct, then one should think in terms of central massive objects, either SBHs or Compact Stellar Clusters (CSCs), that accompany the formation of almost all early-type galaxies. In this observational frame, the hypothesis that galactic nuclei may be the remains of globular clusters driven inward to the galactic center by dynamical friction and there merged, finds an exciting possible confirm. In this short paper we report of our recent results on globular cluster mergers obtained by mean of detailed N -body simulations.

Globular cluster merging in the galactic centers

The Virgo Cluster Survey performed by Côté et al. (2006), by mean of the ACS on the Hubble Space Telescope, has given evidence of the presence of compact nuclei at the photocenters of many early-type galaxies in the cluster, whose luminosity distribution is much better fitted by an extended (King’s) profile rather than by a point source (see Böker et al. 2002, for a similar finding in late-type spirals). The half mass radii of nuclei, r_h , are in the range $2 < r_h [\text{pc}] < 62$, with $\langle r_h \rangle = 4.2$ pc, and correlate with the nucleus luminosity: $r_h \propto L_n^{0.5 \pm 0.03}$. The mean of the frequency function for the nucleus-to-galaxy luminosity ratio in nucleated galaxies, $\log \eta = -2.49 \pm 0.09$, is indistinguishable from that of the SBH-to-bulge mass ratio, $\log(M_{BH}/M_{gal}) = -2.61 \pm 0.07$, calculated in 23 early-type galaxies.

On these bases, Côté et al. (2006) argue that resolved stellar nuclei are the low-mass counterparts of nuclei hosting SBHs detected in the bright galaxies. If this view is correct, then one should think in terms of central massive objects, either SBHs or CSCs, that accompany the formation and/or early evolution of almost all early-type galaxies.

It is clear that these characteristics of early-type galaxies nuclei well fit into a scenario of multiple globular cluster (GC) merging in the inner galactic regions, corresponding to a “dissipationless” scenario as alternative to the “dissipational” scenario, this latter being based mainly on speculative hypotheses (see, e.g., Babul & Rees 1992) supported just by some quantitative results (Mihoš & Hernquist 1994). The validity of the “dissipationless” hypothesis requires, at first, a detailed N -body simulation of the interaction of stellar clusters in the inner regions of their parent galaxy, keeping into account both the cluster-cluster and the cluster-galaxy dynamical interaction. This latter depends on

tidal distortion, acting on the cluster internal motion, and on dynamical friction, acting on the cluster orbital motion. Not many simulations have been presented in the literature that study the possible formation scenarios for Nuclear Clusters (NCs). Among these, we remind those by Fellhauer & Kroupa (2005) finding that super-massive star clusters, like W3 in NGC 7252, are very likely the merging remnants of objects spanning a range of masses from ω Cen scale to that of ultra-compact dwarf galaxies up to very small dwarf ellipticals. Interestingly enough, the resulting super cluster is a stable and bound object, whose density profile is well fitted by a King profile, even if mass loss of the merger product occurs through every perigalacticon passage. Also Bekki et al. (2004) examined a merger formation scenario in which NCs are the product of multiple merging of star clusters in the central regions of galaxies. Bekki et al. simulations are done in a simplified way, neglecting the role of the galactic external potential and with a relatively low resolution. Therefore, it is not clear how realistic are their interesting results showing (i) the full merging of the interacting clusters in a significantly short time ($\sim 10^7$ yr), (ii) the triaxiality in the merger configuration and (iii) the existence of scaling relations among velocity dispersion, luminosity, effective radius, etc..

The Simulations

Here we report briefly of some of the results presented in Capuzzo-Dolcetta & Miocchi (2007) where we studied whether and how the merging of various massive GCs decayed by dynamical friction in the inner galactic region may occur.

The main questions to answer are: (i) given some (realistic) initial conditions for a set of GCs which experienced a significant orbital decay, are they undergoing a full merge? (ii) if so, what is the time needed? (iii) what is the final structure of the merged supercluster? (iv) does it attain a quasi-steady state?

The answers to these question are of overwhelming importance to give substance to the interpretation of the formation of early type galaxy nuclei via merging of decayed GCs, a hypothesis raised first by Tremaine et al. (1975) and subsequently extensively studied by Capuzzo-Dolcetta and collaborators (see Capuzzo-Dolcetta & Vicari (2005) and references therein). We consider GCs as N -body systems moving within a triaxial galaxy represented by an analytical potential, subjected also to the deceleration due to dynamical friction. We studied the merging process occurring among four GCs already decayed in the inner region of the galaxy. The galaxy where the GCs move is represented by a self-consistent triaxial potential. In this potential, the dynamical friction yields decaying times significantly shorter than the Hubble time (Capuzzo-Dolcetta & Vicari 2005). We have simulated 4 massive GCs having an initial King profile with total mass, central velocity dispersion and core radius ranging in $M = 42 - 54 \times 10^6 M_\odot$, $\sigma_0 = 25 - 36 \text{ km s}^{-1}$, $r_c = 2.2 - 3.8 \text{ pc}$. They are initially located within 100 pc from the galactic center (Fig. 1). Simulations are done with the parallel ‘ATD’ N -body code (Miocchi & Capuzzo-Dolcetta 2002), with a total of 10^6 particles.

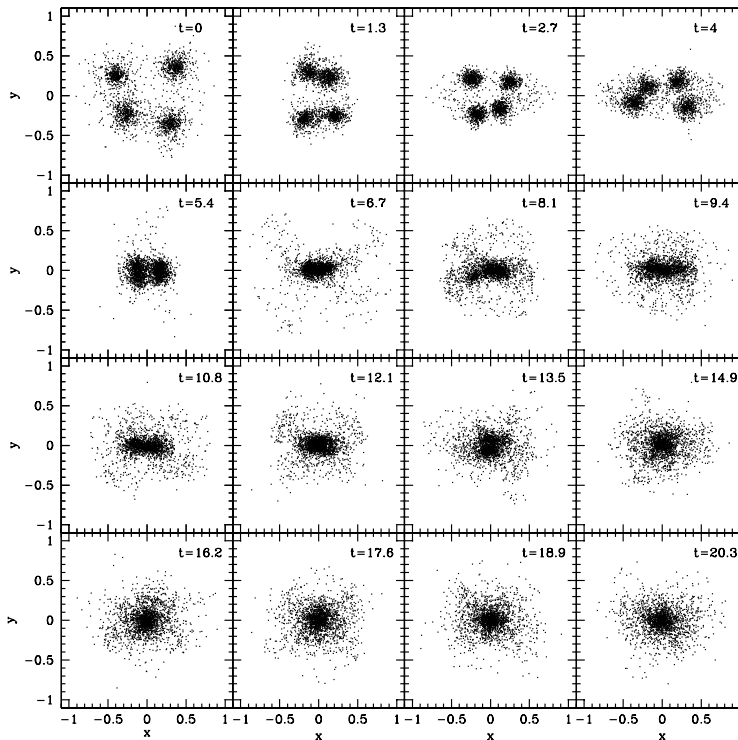


Figure 1. Snapshots of the clusters evolution (projected on the x - y plane) from $t = 0$ to $t = 20.3$ Myr. Lengths are in units of 200 pc and time is in Myr.

Results

The merging occurs rather quickly: after ~ 15 Myr, corresponding to ~ 20 galactic core crossing times (t_{cross}), the merging is completed and the resulting system attains a quasi-equilibrium configuration (see Fig. 1). The total projected density profile in the nuclear region is remarkably similar to those recently observed in the central regions of nucleated early-type galaxies in the Virgo cluster (Fig. 2). The final CSC morphology is that of an axisymmetric ellipsoid (axial ratios 1.4:1.4:1, ellipticity ~ 0.3) without figure rotation. In the velocity dispersion-mass plane, the CSC is located closer to the scaling relation followed by GCs than to that of elliptical galaxies. This is due to that our system is located deep inside the galaxy potential.

Conclusions

We studied the modes of interaction of a few (4) globular clusters which, due to their large initial masses, have experienced a significant dissipation of their orbital energy by dynamical friction caused by the galactic triaxial field. The GC motion in the inner galactic region is characterized by a further barycenter

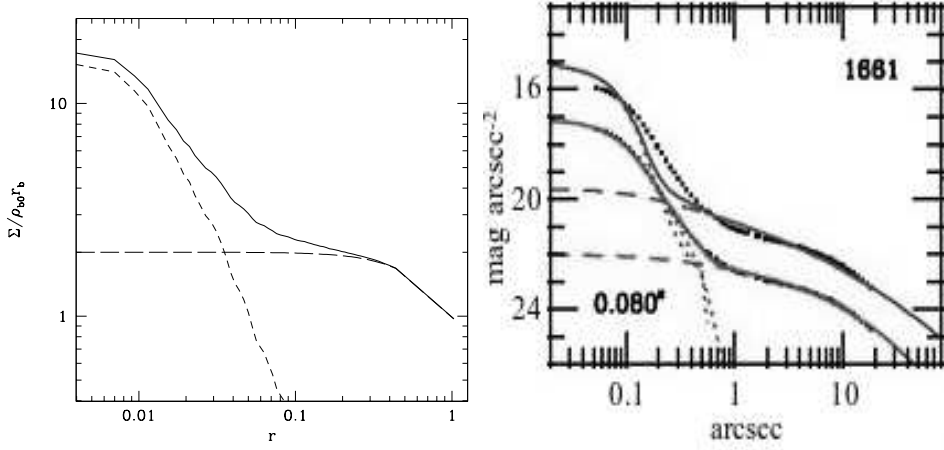


Figure 2. Left panel: Surface density profile (in proper units) for our last computed CSC configuration (short dashed line), overlapped to the galaxy profile (long dashed) so to give the total density (solid line). Right panel: surface brightness profile of NGC 1661, where the lower solid line is the King's model fitting to data (black dots) and the upper solid line is the point source fitting. Dashed line is the galaxy contribution. All the curves are translated for display convenience. The median half light radius ($0.080''$) is reported. (from Côté et al. 2006).

braking due to the galactic tidal torque, followed by a full merge that is completed in $\sim 20 t_{cross}$. The merger result keeps some of the characteristics of the preexisting objects, leading to a single cluster with a King density profile plus a halo which is diffusing in the external field. Due to this, we can speak with some confidence of a secularly stable Compact Star Cluster. Even in the limits of our simulations (both on the number of merging objects and on the integration time, which covers $\sim 45 t_{cross}$), we may extrapolate from our results that the nuclei of many early-type elliptical galaxies may have formed by the merging of few tens of GCs massive enough to have decayed into the inner galactic regions in a time short compared to the Hubble time and compact enough to survive to the tidal stresses.

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